CHAPTER VIII
TRAFFIC CONTROL DEVICES

SECTION 8-02 TRAFFIC SIGNALS

8-02.1 GENERAL. Traffic signals are electrically powered traffic control devices which warn or direct vehicular and pedestrian traffic to take some specific action. Traffic signals provide for the orderly assignment of right of way to conflicting traffic movements at intersections.

Traffic signals are not a complete solution for traffic problems. Traffic signals can sometimes create additional congestion and cause additional delay to vehicles if improperly designed, installed, or maintained. Correctly designed and operated traffic signals installed at warranted locations will provide for the orderly movement of traffic, increase the intersection capacity, and in some instances, tend to reduce accidents.

Traffic signals are listed on the Highway Right of Way and Construction Program in the description of the type of improvement if there is a probability of future signal control. If it is that found signals cannot be justified, they should be eliminated from the program at the earliest possible date.

8-02.2 OBTAINING TRAFFIC COUNTS. All traffic volumes used to warrant traffic signals and develop signal plans are obtained from the Transportation Planning Division or the Transportation Management System database. The Transportation Planning Division furnishes three types of traffic volumes: program, location study, and design. Design traffic volumes include volumes that are projected to the year the project is to be completed (Construction ADT) and volumes that are projected 20 years beyond project completion (Design ADT). Construction year projected volumes are used to warrant signals and develop signal plans. *The Design year (20th year) projected volumes are not used to warrant signals but are requested to determine future geometric requirements.* If the 20-year projection shows signals would be warranted, a 10-year count should be requested. If signals are warranted based on the 10-year count, provisions for future signal installation shall be made (see Subsection 8-02.17 (6)). When requesting traffic volumes from the Transportation Planning Division, the letterhead should state "TRAFFIC VOLUME REQUEST FOR SIGNAL WARRANTS". This will alert the Transportation Planning Division as to the type of traffic volumes required. Projected ADT volumes and turning movements are furnished on Form HP-770. A sample of this form is shown in Figure 8-02.6. It is very important to request the percent peak hour on major and minor approaches if warrants are based on projected traffic. Percent peak hour is the percentage of ADT that occurs in the peak hour. The percent peak hour is not the same as the "Peak Hour Factor" (PHF) used in making a capacity analysis.

8-02.3 WARRANTS. Justification of traffic signals is developed on Form D-22. This form can be found in the Design Forms on the computer system. Form D-22 is required on all new signal locations and existing signals that are being upgraded from temporary to permanent signals or where significant geometric or signal revisions are being made. This form should be completed by district Design, with assistance from district Traffic personnel. It is not necessary to complete all eleven warrants on the form (i.e. If Warrant 1, Eight-Hour Vehicular Volume, is satisfied, Warrant 3, Peak Hour, does not have to be filled out). Traffic counts, or Form HP-770, must be completed and accompany Form D-22. A location sketch or title sheet showing the location of the intersection and any available drawings showing the existing or proposed intersection layout should be included with the warrants. Signal upgrades, such as the addition of interconnect, vehicle actuations, replacement of control equipment or minor geometric revisions do not require Form D-22. Traffic counts or Form HP-770 are not required for these type of upgrades, but may be desired in evaluating the need for improvements or determining signal timing. The district will be responsible for approving the warrants.

Traffic signals are installed only when one or more of the warrants given in Form D-22 is satisfied. The warrants correspond to the warrant numbers in the Manual on Uniform Traffic Control Devices Millennium Edition (MUTCD). When signal warrants are satisfied, basic lighting at the intersection is also warranted (see Section 8-01).

When installation of a traffic signal is warranted, the cost of the signal, its installation and maintenance, and electrical power for its operation, except as otherwise herein provided, will be borne by the Commission. Where possible, the state takes advantage of any reduced power rates by including in the municipal and/or county

agreement a phrase whereby the city will pay for the power, with reimbursement to be made by the state.

Where city/county power is not available, the state pays for the power directly.

When the posted speed limit or field measured 85th-percentile speed on the major street exceeds 40 mph [60 km/h], or when the intersection is located in a community having a population of less than 10,000, the volume of traffic to satisfy these warrants can be 70 percent of the stated values. Seventy percent values are shown in Figure 8-02.2 and on Form D-22.

8-02.3 (1) WARRANT 1 – EIGHT-HOUR VEHICULAR VOLUME.

8-02.3 (1) (a) CONDITION A – MINIMUM VEHICULAR VOLUME. This warrant is based upon present (current) traffic volumes at an intersection. The volume warrant is used when the volume of intersecting traffic is the principal reason for consideration of traffic signal installation. The warrant is satisfied when the traffic volumes given in Figure 8-02.2 for Warrant 1 Condition A exist on the major street and higher volume minor street approaches for each of eight hours of an average day.

Major and minor street volumes shown on this warrant must occur during the same eight hour period. The volumes used for the minor street may be on one approach during some hours and on the opposite approach during other hours. Traffic counts must be attached to Form D-22 when this warrant is used.

8-02.3 (1) (b) CONDITION B – INTERRUPTION OF CONTINUOUS TRAFFIC. This warrant is also based on present (current) traffic volumes at an intersection. The interruption warrant is used when the traffic volume on the major street is such that traffic on an intersecting minor street suffers excessive delay or hazard in entering or crossing the major street. The warrant is satisfied when the traffic volumes given in Figure 8-02.2 for Warrant 1 Condition B exist on the major street and higher volume minor street approaches for each of eight hours of an average day.

Major and minor street volumes shown on this warrant must occur during the same eight hour period and under the same conditions explained in Warrant 1 Condition A. Traffic counts must be attached to Form D-22 when this warrant is used.

The 80 percent columns in Figure 8-02.2 may be used for a combination of Conditions A and B. The major and minor street volumes shall be for the same eight hours for each condition; however, the eight hours satisfied in Condition A shall not be required to be the same eight hours satisfied in Condition B. On the minor street, the higher volume shall not be required to be on the same approach during each of the eight hours.

8-02.3 (1) (c) WARRANT 1A – CONDITION A – MINIMUM VEHICULAR VOLUME, AND CONDITION B – INTERRUPTION OF CONTINUOUS TRAFFIC. These warrants are based on projected traffic volumes for the construction year at an intersection. The Transportation Planning Division furnishes projected ADT volumes on Form HP-770. A factor, determined from the percent peak hour, is applied to the ADT volume on the major and higher volume minor street approaches to obtain the lowest hour of the eight highest hours (8th hour).

A method of estimating the 8th hour, based upon the projected peak hour, is as follows:

% Peak Hour	Factor to Obtain 8th Hour
7	0.0614
8	0.0600
9	0.0586
10	0.0571
11	0.0557
12	0.0543
13	0.0529
14	0.0514
15	0.0500

The warrants are satisfied using the same procedure as outlined for Warrant 1 Condition A or B.

8-02.3 (2) WARRANT 2 – FOUR-HOUR VEHICULAR VOLUME. This warrant in the MUTCD is based on existing traffic and is not normally used by designers during project development.

8-02.3 (3) WARRANT 3 - PEAK HOUR, CONDITION A – MINIMUM VEHICULAR VOLUME AND CONDITION B – INTERRUPTION OF CONTINUOUS TRAFFIC. The need for a traffic signal may exist at locations for peak hours of traffic demand. In order to provide a criterion for evaluation of a heavy peak hour location, a warrant has been adopted for public street, industrial or plant entrances, and public institutions.

The warrant for a traffic signal installed under peak hour volume consists of a modification to the volumes used for an eight hour time period. The construction ADT volumes for the highest (peak) hour and highest two hours, required to satisfy signal Warrant 3, Condition A or B, are shown in Figure 8-02.2.

Unless the signal is to become a part of a progressive signal system, traffic signals installed under this warrant will be traffic actuated.

The type of signal control at an industrial plant or factory entrance will be traffic actuated. This method of control will guarantee a minimum period of right of way to the state highway. Upon actuation of the entrance loop, a pre-determined range of green time will be available to the entrance traffic. Outside of the warranted peak hours, this traffic signal will operate in a flash mode. This flash operation will be yellow for the state highway and red for the entrance. The plant or factory will be required to execute a traffic control easement.

8-02.3 (3) (a) INSTALLATION COSTS.

8-02.3 (3) (a) 1. PUBLIC STREET OR PUBLIC INSTITUTION ENTRANCE. A traffic signal will be installed when the need is established by a traffic study and the intersection meets the signal warrant. The entire cost of the signal (installation, power, and maintenance) will be borne by the Commission. A signal to be installed under this policy will be placed on the Highway Right of Way and Construction Program and scheduled to allow orderly development of the plans and acquisition of right of way.

8-02.3 (3) (a) 2. INDUSTRIAL PLANT OR FACTORY ENTRANCE. The plant or factory owner provides, at no cost to the state, the traffic signal and the intersection geometric improvements. The signal and geometric improvements are designed and constructed in accordance with existing Commission practices. The traffic signal, after installation, becomes the property of the state. At no cost to the plant owner, the state will provide power, maintain, replace, or upgrade the traffic signal at its discretion in order to provide a satisfactory level of service.

8-02.3 (3) (a) 3. COMMERCIAL ENTRANCES. These signal installations are usually completed through the permit process. These are permanent signals. When a design project is in an area where a commercial

entrance meets signal warrants, the state should install signals.

8-02.3 (4) WARRANT 4 - PEDESTRIAN VOLUME. This warrant is based on vehicular volume on a major street and the pedestrian volume desiring to cross the major street during an eight hour time period. This warrant can be used at intersections and mid-block locations. The warrant is satisfied when the required volumes given on Figure 8-02.2 exist on the major street and pedestrian volumes required are met for an eight hour time period. See the MUTCD for additional guidance.

8-02.3 (5) WARRANT 5 - SCHOOL CROSSING. This warrant is based on the procedure outlined in the MUTCD and the book "A Program for School Crossing Protection". A study of the frequency and adequacy of gaps in vehicular traffic, as related to the number and size of groups of school students desiring to cross the street, must be made. The warrant is satisfied when the study shows that the number of adequate gaps in vehicular traffic, during the period when students are crossing, is less than the number of minutes in the same period. A pedestrian delay time study and a pedestrian group size study must be submitted with this warrant. The School Crossing signal warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 300 ft. [90 m], unless the proposed traffic control signal will not restrict the progressive movement of traffic. See the MUTCD for additional guidance.

A contract for adult operation and supervision must be executed with school authorities.

8-02.3 (5) (a) POLICY ON SCHOOL CROSSING SIGNAL. When authorized school or city officials request a school crossing signal which does not meet Warrant No. 5, those parties concerned should be informed of the following criteria with which a signal may be installed at their expense:

- Mid-block installation only unless otherwise authorized by the Design Division.
- No adjacent usable traffic signal within 1000 ft. [300 m].
- Standard contract for school crossing with provisions for removal when usage is below 50% of design warrants.
- Entire cost of installation, maintenance, and operations by others.
- 75% of the volumes of Warrant No. 5 are met.

When adequate school crossing signals are in place prior to a roadway construction project, they are replaced, revised or relocated at the expense of the Commission.

8-02.3 (6) WARRANT 6 - COORDINATED SIGNAL SYSTEM. This warrant is based on the premise that vehicular traffic has a tendency to disperse, spread out, and increase headways between signalized intersections. Such being the case, it is desirable to re-group vehicles or effectively regulate group speed. The warrant is satisfied when

- On a one-way street, or on a street which has predominantly unidirectional traffic and signalized intersections are so far apart that they do not provide the necessary degree of vehicle platooning and speed control.
- On a two-way street when adjacent signals do not provide the necessary degree of platooning and speed control and the proposed and adjacent signals can constitute a progressive signal system.

Installation of a signal using this warrant should not be considered when the resultant signal spacing would be less than 1000 ft. [300 m].

8-02.3 (7) WARRANT 7 – CRASH EXPERIENCE. This warrant is based on accident experience at an intersection. The warrant is satisfied when all of the following criteria are met:

- Adequate trial of less restrictive remedies such as speed zone control, sign control, lighting, flasher, law enforcement, etc., has failed to reduce accident frequency.
- Five or more reported accidents of types susceptible to correction by traffic signal control have occurred within a 12-month period with each accident involving personal injury or property damage to an extent of $100 or more.

- Value required to satisfy Warrant 1, Condition A or B, or Warrant 4 is met to 80 percent.

Accident records and supporting data must be submitted on this warrant.

8-02.3 (8) WARRANT 8 - ROADWAY NETWORK. This warrant in the MUTCD is based on existing traffic and is not normally used by designers during project development.

8-02.3 (9) POLICY ON FIRE STATION SIGNAL. If a definite hazard exists where emergency vehicles enter the highway from an adjacent fire station, and a fire district or city requests a signal on a proposed or existing multi-lane roadway, consideration for a signal should be given if the fire district or city is willing to pay 50% of the cost of construction, and executes a standard contract between the Commission and themselves covering installation and maintenance of such a signal.

The signal indications for the traffic on the street are a 12 in. [300 mm] red, a 12 in. [300 mm] yellow, and an 8 in. [200 mm] yellow. The 8 in. [200 mm] yellow will flash until the fire station signal is activated. The traffic on the street has two signal heads per approach. One signal head is located horizontally over the roadway. The other signal head is located on the signal post. Both signal heads have the appropriate "Emergency Signal" sign located adjacent to the indication. One signal head faces the direction of approach of the emergency vehicle. The indications for this approach are a 12 in. [300 mm] red and a 12 in. [300 mm] green. See Figure 8-02.4 for a standard application of a fire station signal. An “Emergency Vehicle” (W11-8) sign with an “Emergency Signal Ahead” (W11-12P) supplemental plaque, shall be placed in advance of all emergency vehicle traffic control signals.

Normally a push button is located in the fire station. The push button and the conduit to the MoDOT system will be provided by the fire station.

When fire station signals are in place prior to a roadway construction project, they will be replaced, revised or relocated at the expense of the Commission.

8-02.4 TRAFFIC SIGNALS IN URBAN AREAS. In municipal areas, the state designs and constructs traffic signals only at warranted locations, such as:

- The intersection of a state or federal highway with a city street.
- The intersection of an off-ramp from a state or federal highway with a city street.
- The intersection of an on-ramp to a state or federal highway with a city street, when signal control of traffic at the on-ramp is necessary for efficient control of traffic at an adjacent signal-controlled off-ramp. Exception to this is when the on-ramp is located on a city street with existing progressive signal control, in which case the city is responsible for proper control of the traffic at the on-ramp.
- The intersection of an on-ramp to a state or federal highway with a city street, when the intersection or signal appurtenances are located on a state constructed and owned bridge.
- The intersection of two or more city streets directly adjacent to a proposed state designed and constructed traffic signal installation, when the city intersection must be considered a part of the state's signal controlled intersection for purposes of traffic operations through the combined intersection. This condition will normally exist for locations with distances of 100 ft. [30 m] or less between the two intersections.

8-02.4 (1) INTERCONNECT SYSTEM. When the proposed signalized intersection is located within an existing or proposed interconnected signal system, the method of control must be compatible with the existing system in order to maintain the existing progression insofar as is practical. This can be accomplished by a properly coordinated traffic-actuated control.

8-02.4 (1) (a) INTERCONNECTION. If interconnection for supervised operation of control exists between the city's signalized intersections, the state's controller will be interconnected to the city's system provided the proper written agreements to guarantee effective and efficient supervision of the state's equipment are obtained from the municipality.

8-02.4 (1) (b) NON-INTERCONNECTION. If progressive timing is employed, but no interconnection for supervised

operation exists between the city's signalized intersections, the state's control equipment is designed to operate independently of the city's system. However, the controller timing operations are such that all practical effort is made to maintain the existing progressive system.

8-02.4 (2) COORDINATION WITH ADJACENT SIGNALS. In municipal areas, it is necessary for the state to coordinate proposed state constructed signals with municipal or county signals as follows:

- If adjacent intersections on the same street are within 1/4 mile [0.4 km] of a proposed state constructed signal installation and have existing signal control.
- If adjacent intersections require signal control for effective and efficient operation of the state's signalized intersection.
- If adjacent intersections are likely to require signal control in the foreseeable future.

A written agreement with the municipality is obtained by the district, which clearly enumerates the extent of municipal participation in the coordination or installation of adjacent signal controlled intersections, including type of signal control, degree of standardization with respect to signal locations, indications, etc., and a time limit for municipal compliance with the written agreement. Supervisory control equipment is provided by the state to ensure retention of state supervision of the system for efficient operation. The construction of traffic signals at these locations is not a state responsibility, except as previously stated, but every effort is made to ensure ultimate efficient signal operation for state constructed signalized intersections.

8-02.4 (3) ISOLATED LOCATION. When the proposed signalized intersection is not located within an existing progressive system, or if such a system will not be in existence in the near future, the method of control to be employed is traffic actuated, with detector actuation provided for most or all approaches to the intersection.

8-02.4 (4) PARKING RESTRICTIONS. Parking is restricted from all shoulders, and is entirely eliminated on major streets wherever practical, since parking decreases capacity, impedes traffic flow, and increases accidents. A restriction of parking for some 150 ft. [45 m] or more back from the stop line on each approach of the side streets provides the same increased capacity benefit as widening the pavement, and in some instances, permits the creation of auxiliary turning lanes.

Minimum parking restrictions at intersections are given in Chapter IV. Only parallel parking is permitted. Parking is restricted at signalized mid-block pedestrian and school crosswalks a minimum of 100 ft. [30 m] prior to and 20 ft. [6 m] beyond the crosswalk.

The agreement with municipalities covering the operation and maintenance of state-installed and owned traffic control signals and devices, must include provisions for the restriction of parking.

8-02.4 (5) BUS STOPS. If mass transit by commercial busses is involved at a signalized intersection, careful consideration shall be given for the location of bus stops and pedestrian crossings. The location of these stops and crossings should be located in an area that will provide the least disruption to traffic signal operations.

Where practical, bus stops are located on the far side of the intersection area away from signal control. Local traffic operational and enforcement agencies, as well as the concerned transit authority, are consulted for approval of proposed bus stop locations.

8-02.4 (6) COOPERATION. In the preliminary design stages of signals located within the municipality, the district confers with the proper authorities in the municipality concerned to clarify and resolve any points of conflict.

8-02.4 (7) AGREEMENTS. The municipal and/or county agreement for a project located within a municipality or county contains the general requirements for cooperation between the state and the city or county for the efficient operations of traffic signals proposed by the state. An additional agreement is executed to cover the operation and maintenance of state-installed and owned traffic control signals and devices, highway lighting, signing and pavement marking (see Subsection 1-03.7). All agreements are reviewed by the Chief Counsel's Office upon receipt of the necessary information from the district. It is important that the agreements be completed as early in the development of plans for construction projects as possible. Copies of all agreements are submitted to

General Headquarters Design for submission to FHWA as part of the Plans, Specifications and Estimate (P. S. & E.) documents.

8-02.5 DESIGN OF SIGNAL INSTALLATIONS. When the various requirements set out in the foregoing subsections have been met, the actual design of the traffic signal installation begins. District traffic is consulted for recommendations concerning the signal control type before design of the preliminary signal layout is started.

8-02.5 (1) STANDARDIZATION. Intersection design, signal locations, indications and sequences are standardized wherever possible for better driver education, response and obedience, particularly in a series of adjacent signal installations. The "Manual on Uniform Traffic Control Devices" is the basis for statewide standardization.

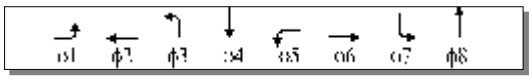
8-02.5 (2) PAVEMENT MARKINGS. If inlaid markings are specified, their location is shown on the roadway plan or special sheet with quantities shown on the 2B sheet. Any other pavement markings are shown on the signal plans with the notation "By Others", which refers to district Traffic.

8-02.5 (2) (a) STOP LINES. Stop lines are normally located 4 ft. [1.2 m] in advance of, and parallel to the nearest crosswalk line. In the absence of a marked crosswalk, the stop line is placed at the desired stopping point, in no case more than 30 ft. [9 m], or less than 4 ft. [1.2 m], from the nearest edge of the intersecting roadway.

8-02.5 (2) (b) CROSSWALK LINES. Crosswalk lines mark both edges of the crosswalk from curb to curb. The width of the crosswalk is usually determined by the width of the sidewalks so connected, but is in no case less than 6 ft. [1.8 m]. If the crosswalk is 100 ft. [30 m] or more in width, the crosswalk line nearest approaching traffic is increased in width from the shoulder or curb to the centerline in order to serve as the stop line. Interior crosswalk lines should meet the curb to discourage diagonal walking between crosswalks.

8-02.6 SIGNAL PHASING. A study of traffic movements at the intersection is made to determine permitted and controlled movements. From this, the number and sequence of traffic phases is determined, which in turn determines the interval or color sequence and types of signal indications to be used. In general, the most efficient operation is obtained with the fewest possible phases; however, each signal installation is designed to provide safe and efficient control of conflicting traffic movements. An exclusive left turn phase should be considered when the number of left-turning vehicles is 100 vehicles or more during the peak hour. If the signal is within a progressive signal system or is interconnected with another signalized intersection, a time-space diagram should be prepared to determine signal phasing. Signal timing programs are available for use with micro-computers to analyze phasing for both interconnect systems and isolated intersections.

Signal phases are identified by directional movement as follows:



In general, phases 1, 2, 5, and 6 are used for the major street, and phases 3, 4, 7, and 8 are used for the minor street. Phases 2, 4, 6, and 8 are normally used to designate through traffic movements. Combined phases are shown with a + symbol (i.e. 1+6, 2+6).

8-02.6 (1) LEFT TURN PHASING. Left turn indications at signalized intersections are designed so they are neither overly restrictive nor inconsistent from the driver's point of view. Protected-only left turns are extremely limiting, therefore they should only be used when tight control is absolutely necessary for a specific approach at an intersection. Warrant worksheets are given in Figures 8-02.11 and 8-02.12 for determining the amount of protection that should be given to a left turn movement. These warrants are based upon accepted capacity values for signalized intersections.

The primary consideration for selecting left turn phasing is intersection capacity. As volumes increase, it becomes increasingly difficult to make permissive left turns. The capacity warrants listed below are divided into three parts: Permissive-Only left turns, Protected/Permissive left turns, and Protected-Only left turns. This

criteria should be used when designing or upgrading a signal installation.

Besides capacity, there are safety reasons for restricting left turn movements. When factors such as sight distance, speed of opposing vehicles, etc. make permissive turns dangerous, the permissive left turn option should be removed. Safety warrants are given under the "Protected-Only Left Turns" section. Safety warrants should be checked first; if an approach requires protected-only phasing for safety reasons, it is unnecessary to check the capacity warrants.

The following terms are used in these warrants:

$V_{LT}Z$ = The left turn volume per hour per approach.

$(V_{LT})_a$ = The adjusted left turn volume per hour per approach.

V_o = The opposing volume per hour per approach per lane.

c = The cycle length (in seconds) when those volumes occur.

g = The green time (in seconds) common to both $(V_{LT})_a$ and V_o during that cycle.

8-02.6 (1) (a) ADJUSTMENT OF LEFT TURN VOLUMES. This evaluation considers the number of vehicles attempting to make permissive left turns. Therefore, the effects of protected left turns should be eliminated. This can be handled using the following method:

$$(V_{LT})_a = V_{LT} - V_P,$$

Where the variable V_p is the number of left turn vehicles served by the protected left turn indication. Assuming that vehicles enter the intersection at a rate of 2 seconds/vehicle, the volume using the protected movement in a one-hour period is:

$$V_P = \frac{T_P \text{ (sec./cycle)}}{2 \text{ (sec./vehicle)}} \times \frac{3600 \text{ (sec./hr.)}}{c \text{ (sec./cycle)}}$$

where T_P is the time allocated to the protected left turn movement. Note that if T_P=O, $(V_{LT})_a = V_{LT}$.

This procedure should be used when evaluating existing installations utilizing protected-permissive phasing or for proposed installations where it is obvious that permissive-only phasing is unacceptable.

8-02.6 (1) (b) PERMISSIVE-ONLY LEFT TURNS. Permissive-Only left turns should be provided when one of the criteria in (1.) is satisfied in conjunction with (2.).

1. $(V_{LT})_a$ <= 100 Vehicles per Hour

   $(V_{LT})_a$ <= 2 Vehicles per Cycle *

   V_o < 100 Vehicles per Hour

2. $(V_{LT})_a + V_o < 600 \times (g/c)$

*Note: This criteria is only valid if observations at the intersection show that drivers tend to make left turns during the clearance interval on a regular basis. These field checks should be made during the hour(s) in which either the highest left turn volume or the highest opposing volume occurs.

8-02.6 (1) (c) PROTECTED/PERMISSIVE LEFT TURNS. Protected/Permissive left turns should be provided when

one of the criteria in (1.) is satisfied in conjunction with one of the criteria in (2.), or when criteria (3.) is satisfied.

1. $(V_{LT})_a$ > 100 Vehicles per Hour and V_o>100 vph

   $(V_{LT})_a$ > 2 Vehicles per Cycle * and V_o>100 vph

   V_o > 100 Vehicles per Hour

   $(V_{LT})_a + V_o > 600 \times (g/c)$

*Note: This criteria is only valid if observations at the intersection show that drivers tend to make left turns during the clearance interval on a regular basis. These field checks should be made during the hour(s) in which either the highest left turn volume or the highest opposing volume occurs.

2. $(V_{LT})_a + V_o < 1200 \times (g/c)$

   $(V_{LT})_a \times V_o < 50{,}000$

3. Number of Observed Traffic Conflict => 29 Conflicts / 11 Hour Day

Note: The number of conflicts are those occurring on the opposite approach that are caused by the subject left-turn movement. Only those approaches satisfying the criteria should be upgraded.

8-02.6 (1) (d) PROTECTED-ONLY LEFT TURNS. Protected-Only left turns should be provided when any one of the following criteria are satisfied.

1. $(V_{LT})_a + V_o > 1200 \times (g/c)$

2. $(V_{LT})_a \times V_o > 50{,}000$

3. Number of Opposing Through Lanes => 3

4. Sight Distance
   < 125' for 20 mph
   < 150' for 25 mph
   < 200' for 30 mph
   < 250' for 35 mph
   < 325' for 40 mph
   < 400' for 45 mph
   < 475' for 50 mph
   < 550' for 55 mph

   < 35 m for 30 km/h
   < 45 m for 40 km/h
   < 60 m for 50 km/h
   < 75 m for 60 km/h
   < 95 m for 60 km/h
   < 120 m for 70 km/h
   < 145 m for 80 km/h
   < 170 m for 90 km/h

5. Number of Correctable Accidents => 5 over 12 months

Note: The five correctable accidents should involve the same left turn approach. Only those approaches satisfying that criteria should be upgraded.

6. Number of Observed Traffic Conflicts => 48 Conflicts / 11 Hour Day

Note: Conflicts occur when motorists on the opposite approach must respond to the actions of motorists making the subject left-turn movement. Therefore, conflicts should be measured by observing the intersection from the opposite approach. Only those approaches satisfying the criteria should be upgraded.

7. Speed (prevailing) => 50 mph [80 km/h] or = 45 mph [70 km/h] and a study indicates that the number of gaps is insufficient to turn safely.

Protected left turn movements should be provided with an adequate turn bay or a separate turning lane, depending upon the volumes using the intersection and the existing intersection geometry. Shared lanes (LT+TH or LT+TH+RT) are undesirable for this purpose and should be avoided.

8-02.6 (2) SIMULTANEOUS LEFT TURNS. The phasing sequence which permits signal-controlled opposing left turn movements to move simultaneously, preceding the through movement, is the most efficient, provided auxiliary left turn lanes are available, left turn volumes are nearly equal, opposing traffic volumes are sufficient to justify simultaneous movements, and the intersection geometric configuration will permit the movements.

8-02.6 (3) LEFT TURNS LEADING OR LAGGING WITH THROUGH MOVEMENT. At locations where a left turn lane is needed but cannot be provided, some relief is achieved by the use of a leading or lagging green period for the direction of traffic with the heavy left turn. When auxiliary left turn lanes are provided, it may be advantageous to lead and lag the left turn movements when volumes are unequal. A time-space study should be made to verify feasibility if the signal is interconnected.

8-02.6 (4) OFF-RAMPS. The phasing for signal controlled interchange exit ramps entering the crossroad is designed to prevent backup onto the freeway through lanes. A method of signal interconnection should be provided between the ramp terminals.

8-02.7 METHOD OF SIGNAL CONTROL. Pre-timed or traffic actuated signals are used as part of interconnect systems. Traffic actuated signals are usually installed at isolated locations. Signalized intersections 1/4 mile [0.4 km] or less apart are interconnected if practical. Signalized intersections spaced up to 1/2 mile [0.8 km] apart should be considered for interconnection.

Where two signalized intersections are less than 300 ft. [90 m] apart, coordination is critical and interconnection should be provided. If actuated control is used, then both intersections should be operated from a single controller with signal phasing that guarantees coordination to the critical movements.

8-02.7 (1) PRE-TIMED SIGNAL CONTROL. This type of control provides a consistent and regularly repeated sequence of signal indications in accordance with a single predetermined time schedule or a series of such schedules.

8-02.7 (2) TRAFFIC-ACTUATED SIGNAL CONTROL. For this type of control, green intervals are determined through input from vehicle and pedestrian detectors. The cycle length and sequence of indications may vary from cycle to cycle, dependent upon the type of controller and the auxiliary equipment specified. Actuated phases are omitted if no demand is made for them. The length of each actuated phase is usually determined by the demands of traffic.

8-02.7 (2) (a) NEMA TS1 CONTROLLERS. This type of controller must meet the specifications outlined in the latest National Electrical Manufacturers Association (NEMA) standard. This standard details the wiring and minimum functions of a controller. Other details specified are items inside the controller cabinet such as detector amplifiers and back panel wiring. This controller is used in all districts.

8-02.7 (2) (b) 170 CONTROLLERS. This type of controller must meet the specifications outlined by CALTRANS Specification 170 and Missouri 170 specifications for signal controllers. The 170 controller is used in Districts 4 and 8 in order to coordinate with the cities of Kansas City and Springfield, respectively.

The type of software to be used in this controller is indicated on the plans. District 4 uses Wapiti software which is furnished with the controller. District 8 uses Bi-Trans software which is provided by district traffic personnel. Two types of cabinets are used with the 170 controller. The larger cabinet is specified as Type 332. The smaller cabinet is specified as Type 336S. The 170 controller cabinets contain input and output "files" which are racks containing card rack detectors and load switches. The configuration of input and output "files" and the type cabinet is specified on the plans. District traffic personnel are contacted for assistance in determining the type of cabinet, the configuration of input and output "files" and any other equipment needed in the cabinet.

8-02.7 (2) (c) SEMI-ACTUATED CONTROL. This type of control is used at signalized intersections where detectors are provided on one or more approaches, but not all approaches, such as the intersection of a heavy volume major street with a relatively low volume minor street, with detectors placed to detect minor street traffic.

The non-actuated phase is equipped with adjustable timing for presetting the green interval and clearance interval. Right of way is returned to this phase at every opportunity by placing the phase on recall. In the absence of actuation from the actuated phase or phases, right of way will "dwell" or remain on the non-actuated phase. When right of way is given to the non-actuated phase the green interval is timed, at the completion of which the controller is permitted to respond immediately to a demand for right of way from an actuated phase.

An actuated phase is equipped with adjustable timing for presetting the traffic variable timing. These settings are as follows: Initial portion, which provides time for standing vehicles to get into motion; unit extension, which provides time for moving vehicle actuating the detector to clear the stop line; maximum green, which limits the continued resetting of the unit extension interval; and the clearance interval.

When right of way is first given to an actuated phase, a minimum green interval is timed. After timing of the minimum green interval, the retention of right of way is dependent upon continuing actuations by vehicles passing over the detector, and will extend the green interval up to the maximum time setting. Each vehicle actuating the detector during this extensible portion cancels any time remaining from the previous unit extension and provides one complete unit extension from the moment of actuation. If an actuation does not occur before a unit extension is timed to completion, right of way is automatically transferred to the non-actuated phase. If right of way is transferred from the actuated phase by the action of the maximum green limit, or if an actuation occurs during the actuated phase clearance interval, right of way is returned to the non-actuated phase.

Fully-actuated controllers are used to operate as semi-actuated controllers by means of a "recall" switch turned to the "on" position for the non-actuated phase. This recalls right of way automatically to this phase in the same manner as a vehicular actuation and guarantees a green interval.

8-02.7 (2) (d) FULLY-ACTUATED CONTROL. This type control is normally used at signalized intersections where detectors are provided on all approaches. Each phase of the controller is provided with four adjustable time settings identical to those provided for an actuated phase for semi-actuated control.

The operation and function of these settings are identical to those for the semi-actuated control, except that in the absence of actuation on any other traffic phase, right of way remains on the phase to which it was last assigned.

The timing of the maximum green for the phase with the right of way does not begin until an actuation or other demand for right of way is made for some other phase and the initial portion has expired for the phase with the right of way.

When two vehicles actuate detectors on two different phases at the same time, the right of way remains on the street to which it was last assigned for sufficient time to allow one of the vehicles to safely traverse the intersection and is then transferred to the other phase to allow right of way for the second vehicle. In addition, continuous traffic on one street is never interrupted unless a vehicle on another approach actuates

a detector, and then that vehicle is allowed to cross at the first gap that appears in the continuous traffic. If no gap appears during a predetermined maximum interval, then the continuous traffic is only halted long enough to permit the vehicle to cross safely.

8-02.7 (3) CLOSED LOOP. A closed loop system is a system of traffic actuated controllers that are interconnected (by hardwire, telephone, radio, fiber, etc.) and are controlled by a master controller (normally located in one of the signal cabinets). The master unit has a communications link to a computer that is located at the district office.

Besides the normal stop bar detectors that are associated with actuated controllers, closed loop systems have additional detectors called system detectors that can be located between intersections, in exclusive turn lanes, or on side streets. These system detectors provide additional information to the master controller (speeds, volumes, queue lengths, etc.). The master controller can then adjust the timing or change cycle lengths to reflect current traffic conditions. The central computer can monitor the system and can be used to make changes to the timing from the office. All closed loop systems must have General Headquarters Design approval.

8-02.8 AUXILIARY EQUIPMENT FOR CONTROLLERS.

8-02.8 (1) COORDINATION INTERFACE.

8-02.8 (1) (a) 7-CONDUCTOR HARDWIRE. This interface is required with all NEMA actuated controllers that are interconnected with 7- or 12-conductor hardwire. This interface is typically a panel installed inside the controller cabinet for terminating the interconnect cable. This interface is indicated on the D-37 sheet. One intersection in the system is designated as the master and the other intersections are designated as locals.

The master controller is placed at a central location in a system or at a key intersection. If possible, several intersections should be visible from the master controller. Where two major routes intersect and interconnect is being provided along both routes, the master should be located at the intersection of the two routes.

Modern actuated signal controllers use internal coordination. In the local controller, the controller software processes inputs from the interface panel to activate the appropriate timing plan and keep the controller "in step" with the rest of the signals in the interconnected system. In the master controller, the controller software produces outputs to the interface panel which are transmitted to the rest of the system via the hardwire interconnect.

8-02.8 (1) (b) TIME-BASED COORDINATION. This type of coordination is used in an interconnected system when hardwire interconnect or closed loop-type interconnect is not being provided. Time-based is specified on the D-37 sheet for NEMA or Type 170 where this type of interconnect is being used.

Time-based coordination is usually an internal function of the controller. An accurate clock is provided in the controller. The controller software uses this clock as a reference to activate the appropriate timing plan and keep the controller "in step" with the rest of the signals in the interconnected system. This is the most economical type of signal interconnect since interconnect conduit and cables are not needed between intersections. The primary drawback to time-based coordination is that the clocks must be periodically synchronized since they will drift over time. A drift of a few seconds can impact the traffic progression.

8-02.8 (1) (c) CLOSED LOOP INTERFACE. This interface is required for all NEMA or Type 170 controllers in closed loop systems. This interface is typically a panel installed in the controller cabinet for terminating the interconnect cable or the connections to other interconnect communications equipment (i.e. telephone, microwave, fiber optic, etc.). The closed loop interface is specified on the D-37 sheet for each intersection in the system. Any other special equipment required for the interconnect system should also be shown on the D-37 sheet.

A master controller unit is required for closed loop systems. This controller is normally installed in the same cabinet as one of the local controllers in the system. The master controller is indicated on the D-37

sheet for the intersection where it is located.

8-02.8 (2) MANUAL REMOTE 'ON - OFF' SWITCH AND CABINET. These are used whenever push button-actuated, pre-timed controllers or any traffic-actuated controllers are used to provide pedestrian crossing signal control for school children under adult supervision. In the "Off" position, the pedestrian signals are extinguished and the pedestrian push buttons are inoperative. Two types are used and depend upon the crosswalk and controller location. Types and uses are explained in the standard specifications.

8-02.8 (3) TIME CLOCK. Solid-state time clocks are used where the signalized intersection is for a school or factory entrance. The time clock provides a period of access to allow an authorized person to operate the signals. The units are to be shown on the D-37C as Time Clock. No separate payment will be made for this item.

8-02.9 MEANING AND APPLICATION OF SIGNAL INDICATIONS. Each driver approaching a signalized intersection should be made readily aware of what movements may or may not be made by means of the proper application of the signal indications themselves, without relying on the use of signs. All traffic signals are to remain in operation either on automatic or flashing unless covered, taken down, or turned away from approaching traffic.

A minimum of two sets of through indications on separate signal heads are provided for each approach to a signalized intersection. The ball green, yellow and red indications in a three-section (permissive-only) or a five-section (protected-permissive) left turn head can be the second set of through indications. On the leg of tee intersections and at ramp terminals where there is no through traffic, a minimum of two sets of indications on separate signal heads are provided for at least one of the turning movements, usually the left turn.

8-02.9 (1) NUMBER OF LENSES. Each signal face, except pedestrian and fire station exit signals, is provided with a minimum of three and a maximum of five lenses, except where a green arrow lens is used alone to indicate continuous movement. The lenses are red, yellow, and green and display a circular or arrow indication. Red arrow lenses are not used.

8-02.9 (2) STEADY CIRCULAR GREEN. This indication is used only when traffic in each lane approaching the signal is permitted to proceed in any lawful direction. Pedestrians facing this indication may proceed with caution across the roadway within any marked or unmarked crosswalk unless directed otherwise by a pedestrian signal.

Where circular green indications are used to control left turn movements, the left turns are permitted (permissive). In this case, the left turns must yield to opposing vehicle or pedestrian traffic. The circular green may be used by itself in a three-section signal head with R - Y - G for permissive only left turns or in conjunction with a green left arrow in a five-section signal head with R - Y - G - YL - L for protected - permissive left turns. In either case, sign R10-12 should be installed adjacent to the signal head.

A steady circular green is also used to control a right turn lane (or combination right/thru lane) where right turning vehicles must yield to pedestrians in a crosswalk controlled by pedestrian indications. This occurs when a marked crosswalk parallel and to the right of the approaching driver is controlled by pedestrian signal heads.

8-02.9 (3) STEADY GREEN ARROW. Green arrow indications are physically located as near as practical to being directly in line with the movements they control.

An indication for a right turn vehicle is normally not required if there is a channelizing island that creates a "free" right turn. A "free" right turn would normally be controlled by a yield sign.

8-02.9 (3) (a) GREEN STRAIGHT THROUGH ARROW USED ALONE. This indication is used only when traffic approaching the signal is permitted to proceed straight through the intersection. ***Green straight arrows are not used when an opposing left turn is permitted to "yield on green".***

Pedestrians facing this indication may proceed across the roadway within any marked or unmarked crosswalk unless directed otherwise by a pedestrian indication.

A red indication in the same signal face is not illuminated in conjunction with this indication.

8-02.9 (3) (b) GREEN TURN ARROW USED ALONE. This indication is used only when traffic is permitted to proceed into the intersection in the direction indicated by the turn arrow without conflicting with any other traffic movement.

Pedestrians facing this indication are to comply with the meaning of the green turn arrow indication, unless directed otherwise by a pedestrian indication. Pedestrian "WALK" indications are not permitted against turn arrow indications.

When a red indication is illuminated in conjunction with this indication, the green turn arrow is followed by a yellow arrow unless the next phase will continue to display the green turn arrow.

8-02.9 (3) (c) ALL GREEN ARROWS. Green arrows are used to control all vehicular movements from an approach whenever the following conditions are present:

- Traffic in each lane is only permitted to proceed in a specific direction.
- All lanes on the approach are exclusive.
- The movement does not conflict with any other movement.

8-02.9 (4) GREEN TURN ARROW WITH CIRCULAR GREEN. Green turn arrows are located in the same signal face with a circular green indication only to indicate the protected leading or lagging portion of the green interval. When a protected turning movement is to become a yielding turning movement, the green turn arrow is cleared with a yellow turn arrow. The red, yellow, and green circular indications mimic the adjacent through phase. A lagging protected turn movement does not require a yellow turn arrow for clearance.

8-02.9 (5) SIGNING A TURN MOVEMENT. When a turn movement is protected and controlled by a three-section head consisting of red, yellow arrow, and green arrow, an R10-10 series sign is specified on the post or mast arm supporting the signal head except at ramp terminals and the leg of tee intersections where there is no opposing through traffic.

An R3-5 series sign is located over the left turn lane when practical and in all instances when through vehicular traffic may become trapped in the left turn lane. Mast arms located at the edge of the traveled way should not be lengthened or extended for the sole purpose of providing this sign.

Signal signs are listed on the D-37A sheet. The quantity and total area of each sign should be indicated, along with the total area of all signal signs for the Signal Sign pay item.

8-02.9 (6) STEADY YELLOW. Except as noted below, each green indication is followed by a steady circular yellow indication to provide clearance for traffic within the intersection and to warn approaching traffic that the red indication will be shown immediately thereafter. Unless otherwise directed by a pedestrian signal, pedestrians facing this indication are thereby advised that there is insufficient time to cross the roadway.

No circular green or green arrow indication or flashing yellow indication is terminated directly into a steady red or flashing red indication without the display of the steady yellow clearance interval. An exception to this rule is the signal face for a fire station exit.

When a left turn clearance interval occurs simultaneously with the clearance interval for same direction through traffic, the steady yellow indication is displayed to both movements for the duration of the clearance interval.

The steady yellow indication is not used in any transition from steady red or flashing red indication to circular green, green arrow, or flashing yellow indication.

The circular yellow indication is not shown simultaneously with circular green or red indication in the same signal face.

Steady yellow is not used as a caution signal.

8-02.9 (7) FLASHING YELLOW (Caution Signal). A flashing yellow indication is used only to warn traffic approaching the signal to proceed through the intersection with more than ordinary caution. In no case is a traffic signal installation to flash yellow for all traffic entering the intersection.

Transition from normal operation to flashing yellow operation is only made directly from steady circular green or green arrow indications.

8-02.9 (8) STEADY RED. A steady red indication is used following the yellow clearance interval to stop approaching traffic back of the stop line or cross walk on the near side of the intersection. A steady red indication requires traffic to remain stopped until the green indication is again displayed. No pedestrian facing this indication is to enter the roadway unless they can do so safely and without interfering with any vehicular traffic, or unless a separate "WALK" indication is shown.

Left turns are not made during the illumination of the steady red indication without a concurrent green arrow.

Right turns are normally allowed on a steady red indication after stopping. In some cases due to poor sight distance, intersection geometric configuration (i.e. a five-approach intersection) or signal phasing, right turns are prohibited on red. Where this is the case, sign R10-11a, No Turn On Red, is installed.

Although red arrows are permitted in the MUTCD, they are not used in MoDOT designed signal projects.

8-02.9 (9) FLASHING RED (Stop Signal.) A flashing red indication is used to stop approaching traffic in the identical manner as a steady red indication except that once stopped, the right of traffic to proceed is subject to the rules applicable after making a stop at a "STOP" sign. Stop signs are not used to supplement signal indications at signalized intersections even though the traffic signals may be on flashing red for part of the day or at irregular intervals. Stop signs may be used when a minor street or driveway is located within or adjacent to a signalized intersection when the vehicular volume from the approach is 50 vehicles per day (24 hours) or less.

Transition from normal operation to flashing red is only made after display of a steady circular yellow indication.

8-02.9 (10) OPTICALLY LIMITED (OL) SIGNAL HEAD. At locations where drivers view conflicting signal indications such as closely spaced intersections, the signals at the second or successive intersections may be optically limiting in both directions.

This signal head can also be used at locations where streets intersect at an acute angle and the signal indications for two or more approaches to the intersection are visible to the approaching motorist. Past practice in this situation was to veil the conflicting signal indications from the motorist by using tunnel visors and louvers. The OL signal head is not to be used as a replacement for tunnel visors and louvers at all locations but rather at locations where a definite hazard exists to the approaching motorist who views signal indications for an approach other than the one they occupy. The OL signal should be centered on the approach which it is to control. Near side locations should be avoided.

A single section of the OL head can be combined with conventional sections.

8-02.9 (11) TUNNEL VISORS AND LOUVERS. Tunnel visors are provided on all signal indications. Louvers are provided for specified signal indications at locations where the angle of visibility of the signal to approaches other than the one it is intended to control is such that a possibility of confusion to drivers may occur as to which signal they are to obey. The circular red indication maybe louvered on signal heads governing left turn only movements (three-section heads consisting of red, left yellow, and left green turn arrow). This will prevent drivers in the adjacent through lane from seeing both a red and a green indication as they approach the intersection. Louvers are not used on five-section left turn heads since the ball green, yellow and red indications are displayed the same as for the adjacent through lanes.

Depending on the traffic phasing, the red and yellow indications may sometimes be the only indications that

require louvers. Determination of the type of louver to specify is made from examination of the planned location and direction of aiming of the particular signal face and the angle of obscurity as shown on Figure 8-02.7. Green and yellow arrow indications are not louvered.

8-02.9 (12) PEDESTRIAN CONTROL. "DON'T WALK" and "WALK" signal indications are used only at warranted locations to control pedestrian traffic. During the time traffic signals at the intersection are on flashing operation the pedestrian signals are not illuminated.

8-02.9 (12)(a) STEADY "WALK". A steady "WALKING PERSON" indication is used only when pedestrians facing this indication are permitted to cross the roadway within any marked or unmarked crosswalk without conflicting with any other traffic movements.

8-02.9 (12)(b) FLASHING "DON'T WALK" PEDESTRIAN CLEARANCE. Each "WALKING PERSON" indication is followed by a flashing "HAND" indication to allow any pedestrian facing this indication who has partially completed their crossing during the "WALK" interval to proceed to a sidewalk, or to an island if one is provided, and to warn approaching pedestrians that they are not to start to cross the roadway as there is insufficient time available to complete such crossing.

This indication is caused to flash to distinguish the pedestrian clearance interval from the steady "DON'T WALK" interval of the signal cycle.

8-02.9 (12)(c) STEADY "DON'T WALK". A steady "HAND" indication is used following the clearance interval to require pedestrians facing the signal to remain out of the crosswalk until the "WALKING PERSON" indication is again displayed.

8-02.10 LOCATION OF SIGNALS AND APPURTENANCES.

8-02.10 (1) VEHICLE SIGNAL FACES. A signal face contains from one to five signal lenses provided for controlling traffic in a single direction. Turning indications may be included in a signal face. A signal head is an arrangement of one or two signal faces. Indicators of 12 in. [300 mm] are provided at all locations, except for preempt signals where an 8 in. [200 mm] flashing yellow is provided. All signal faces are provided from the manufacturer with backplates and tunnel visors.

A minimum of two signal faces are provided for each approach to a signal controlled intersection. The signal faces are located on the far side of the intersection to guarantee visibility of at least one signal face to each approaching vehicle. Both signal faces should be located within a 40 degree zone from the stopping point of approaching traffic centered on the lane the faces control. Signals are optimally located 65 ft. [20 m] from the stopping point of approaching traffic but normally should not be less than 40 ft. [12 m] nor more than 150 ft. [45 m]. When the two far side signal faces are beyond 150 ft. [45 m] from the stop line on the approach they control, a signal face is located at the near right side of the approach. The near right signal is located at the stop line, or as near to the stop line as practical. This near right indication is in addition to the two far side indications.

If the two far side signal faces are to be top- or side-mounted, there should be one face on each side of the approach. When there is only one top- or side-mounted signal, it is located on the far side and supplemented by a mast arm, spread bracket, or span wire signal face. On multi-lane approaches, it is desirable to center each signal face over the lane that the face controls by means of span wire or mast arm support. It is also important that the signal head is centered over the receiving lane to guide vehicles through the intersection. On one lane approaches, it is desirable to have one signal head centered over the receiving lane on a mast arm or span wire support and one head side or top mounted on the far right side. For left turn indications, the signal faces may be offset from the centerline of the lane by 2 ft. [0.6 m] to prevent the signals from blocking the view of the opposing approach.

Signal faces mounted at the side of a street with curbs or an established curb line are located as near as practical to the curb line, but in such a manner that no part of the signal head or its support above ground level is within 2 ft. [0.6 m] of the face of the curb.

Mast arm mountings are preferable to span wire suspension mountings for overhead signals, but each case is decided on its own merits. In general, span wire mounting is only used for temporary signal installations. Mast arm signal posts are steel, and span wire posts may be either steel or wood. A steel span wire post is only used where guy wire for the wood pole cannot be used. Mast arm signal faces controlling through traffic are at least 8 ft. [2.4 m] apart measured horizontally between centers of the faces. Care should be taken to avoid conflict with overhead utility lines.

When protected-only left turn phasing with a three-section left turn head is used, the red indication in the left turn head can be displayed at the same time as the green indications in the heads for the adjacent through movements. In these cases, these signal faces are located where they will not confuse or otherwise unduly influence the same direction through movement.

Separate turning movement signal faces are located transversely as far to the left or right of the same direction through movement as it is practical, and still provide proper signal control of the turn movement. One signal face is provided for each turning lane.

When physical conditions prevent drivers from having a continuous view of at least two signal indications for the following conditions before reaching the stop line, a SIGNAL AHEAD sign should be specified.

TABLE 8-02.1
MINIMUM VISIBILITY FOR POSTED SPEED LIMITS

POSTED SPEED LIMIT (mph)	MINIMUM VISIBILITY DISTANCE (ft.)		POSTED SPEED LIMIT (km/h)	MINIMUM VISIBILITY DISTANCE (m)
20	175		30	53
25	215		40	66
30	270		50	82
35	325		60	99
40	390		60	119
45	460		70	140
50	540		80	165
55	625		90	191
60	715		100	218

8-02.10 (2) PEDESTRIAN SIGNAL FACES. These are located at each end of each controlled crosswalk and are preferably mounted on posts supporting vehicular signal faces, where practical. Posts and bases supporting traffic signals of any type should not obstruct the sidewalk.

8-02.10 (3) SIGNAL POST BASES. All bases for mast arm signals located in islands, behind curbs or beyond shoulders, are Type A. Type B bases are used at high pedestrian traffic locations where the only location for the post is in a sidewalk. A signal head or its bracket should not obstruct the crosswalk or sidewalk. Type C bases are used for post top mounted signals. Signal post bases are not installed in medians less than 4 ft. [1.2 m] in width, face to face of curbs, and are preferably installed only in medians of 6 ft. [1.8 m] width or more. Wherever practical, signal post bases should not be located in median islands or divided highway medians. Median-located signal post bases will have 7 to 10 ft. [2.1 to 3.0 m] of clearance to the median nose. All post bases are located a minimum 2 ft. [0.6 m] behind curbs or 2 ft. [0.6 m] beyond the shoulder. A luminaire may be placed on a mast arm signal post to provide basic lighting without affecting the base design. Care should be taken to avoid conflicts with overhead utilities when installing lights on signal posts.

8-02.10 (4) LOCATION OF CONTROLLERS. Controllers are placed in non-hazardous locations, in such manner that the signal controlled traffic movements can be observed while standing by the controller. Signal controllers are not located in median islands or divided highway medians. Wherever practical, controllers should not be located on right turn islands. Controllers are not located in drainage ditches. If more than one location fulfills

these conditions, the location is selected as determined by the proximity of the source of electrical power and the conduit system.

A rectangular concrete base is used for traffic signal controller cabinets except when the cabinet is mounted on a wood or steel span wire post. For span wire signal installations, contact district Traffic for recommendations concerning controller mounting.

Controller cabinet posts on flush bases are not used. Standard Plans 902.10 and 902.30 show concrete quantities for cabinet bases. The designer determines the type of base to be used and indicates that information on the D-37C sheet.

8-02.10 (5) SERVICE POLE AND POWER SUPPLY ASSEMBLY. If the power source is off of the right of way, a service pole or pedestal for the power supply assembly is located 2 to 4 ft. [0.6 to 1.2 m] inside the right-of-way line as near as practical to the controller location. If the power source is on the right of way, the power supply assembly is located as close as possible to the power source. The placement of the power supply is compatible with adjacent design features. Power supplies are not installed in medians or right turn islands. Only Type 1 (pole-mounted) or Type 2 (pedestal-mounted) secondary service power supplies are used. The Type 2 power supply is the preferred design. If the power source is distant from the controller location, a complete conduit run is provided from the power supply to the controller. For temporary traffic signal installations, it is permissible to use overhead cables between the power supply and the controller.

The location of the service pole or pedestal, and the equipment to be mounted thereon, and the furnishing of power to this assembly are all approved or agreed to in writing by the utility company concerned before final plans are submitted to General Headquarters Design. A copy of this letter is sent to General Headquarters Design with the final plans.

8-02.10 (6) SIGNAL APPURTENANCES ON BRIDGES. When traffic signal appurtenances are to be constructed on a bridge, a detailed layout is submitted to General Headquarters Bridge and General Headquarters Design. The preliminary traffic signal layout should be reviewed by General Headquarters Design prior to submittal of the layout to General Headquarters Bridge. General Headquarters Bridge will provide detail design of the appurtenances on or through the structure. The district's submittal to General Headquarters Bridge should reflect location and size of conduits, post bases, pull boxes, and junction boxes.

8-02.11 DETECTORS. Detectors are devices used with actuated controllers to sense the presence of vehicles or pedestrians to award right of way on the basis of actual demand. Detector location is dependent upon stop line and crosswalk location, therefore, stop line and crosswalk locations should be reviewed with district Traffic before locating detectors.

Each loop or detection zone will require a sensor unit which is housed in the controller cabinet. Sensor units (amplifiers or detectors) with 2-channel card-rack mounted versions will be used. Each 2-channel unit is capable of handling two loops or detection zones. The loop or detection zone associated with each phase should be shown on the detector schedule on the D-37 sheet. Each loop is assigned a card position and channel on the D-37 sheet. Detection zones are not assigned a card position or channel. Suggested assignments are as follows:

Channel Number	Card Position							
	1	2	3	4	5	6	7	8
1	Phase 1	1 or 6	6	6	3	3 or 8	8	8
2	Phase 2	5 or 2	2	2	7	7 or 4	4	4

The quantity of 2-channel detectors is indicated below the assignment chart. Even if only one channel of the two-channel card detector is used, the entire unit is counted as a card detector and is paid for as such. The maximum number of card detectors is 8.

8-02.11 (1) INDUCTION LOOP DETECTORS. This detector may be used for single and multiple lane detection. Operative speed is 0 to 80 mph [0 to 130 km/h] and detection is non-directional. The zone of influence can be

reduced so that actuation will not occur unless the loop is driven upon. This actuation can be presence as well as motion. Parked cars will not affect these detectors. The cost of this type detector is dependent on the number of loops.

Each loop consists of two or more turns of #14 AWG [2.5 mm^2] stranded wire placed in sawed slots in the existing pavement, or in the "B" or "C" course of asphaltic resurfacing. Separate slots for each detector's lead wire to the pull box must be provided for maintenance. The loop wires are spliced to a shielded #14 AWG [2.5 mm^2] lead-in cable in the pull box. The lead-in cable is continuous to the controller cabinet.

Standard loop dimensions are 6 ft. x 30 ft. [1.8 m x 9.0 m] for stop line detection. Advance loop detectors on high speed approaches, closed loop system detectors, or speed detectors are 6 ft. x 6 ft. [1.8 m x 1.8 m]. Standard Drawing 902.50 shows detector configurations. The dimensions of loops are shown on the plans.

Where conditions such as the location of a bridge end do not allow 30 ft. [9 m] for the location of a stop line loop detector, a shorter quadrapole detector may be used. In this case additional detection with a second loop detector or another type of detector should be installed to provide a 30 ft. [9 m] minimum detection zone. Figure 8-02.16 shows a typical layout at a bridge end.

8-02.11 (1) (a) LOCATION OF DETECTORS. Location of detectors is critical with respect to the efficient operation of actuated control, therefore, their location is carefully designed. Loop detectors should not be located in "E" joints, bridge expansion joints or other full depth joints.

8-02.11 (1) (a) 1. DETECTORS FOR LEFT TURN LANES. These detectors are placed as close to the stop line as practical, as this is a relatively slow movement. This location allows a minimum green time and thereby provides the most efficient operation.

8-02.11 (1) (a) 2. DETECTORS FOR THROUGH TRAFFIC. Loop detectors, 30 ft. [9 m] in length, located at the stop line in each lane, are normally used to detect through traffic.

Full traveled pavement detector coverage is essential for efficient operation. Detectors are placed so that no more than a 6 ft. [1.8 m] gap in coverage is allowed across the traveled pavement. When a physical barrier is not provided between opposing flows of traffic, the field of detector actuation should come no closer than 3 ft. [0.9 m] to the centerline.

8-02.11 (1) (b) TIME DELAY UNIT. This unit is used with vehicle detectors to delay the input signal from the detector to the controller. This will prevent "false calls" into the controller which may cause the controller to service a phase where there is no vehicle waiting. Time delay detectors should be used for any of the following conditions:

- Exclusive right turn lanes where right turns are permitted on red.
- Exclusive left turn lanes where there is no adjacent divisional median island.
- Exclusive left turn lanes where protected-permissive left turn phasing (with a five-section signal head) is used.

Time delay detectors may be used in other situations as needed.

8-02.11 (2) VIDEO DETECTORS. Video detection systems may be desirable for pavement preservation, maintenance, or safety reasons. Advantages of this system are that no saw cuts are necessary in new pavement, or where pavement is in poor condition, and sawing could cause further deterioration. Video detection may be used in locations where joint placement prohibits the use of sawed loops. Finally, video detection also has safety advantages, as work in the roadway is not required for installation or maintenance. The cost of a video detection system is approximately twice the cost of a standard induction loop system. The decision to select a video system should include District Traffic personnel and District budget considerations. Video detection systems are paid for as a lump sum unit, which includes the cameras, wire, cable, mounting equipment, monitors, processor units, etc. One camera may be capable of covering more than one detection zone, therefore, the number of cameras will be determined by the contractor, depending on which system is installed, rather than

on the D-sheets.

When plans include retrofitting a new detection system into an existing signalized intersection, check with District Traffic to determine if the existing controller equipment is compatible with the operation of a video detection system before making that selection.

8-02.11 (3) ADVANCE DETECTORS. On approaches with operating speeds of 45 mph [70 km/h] or greater, advance detection should be considered to allow adequate time for a vehicle to pass through the intersection with a green signal indication. A standard 6 ft. x 30 ft. [1.8 m x 9.0 m] loop is located in the desired lane immediately behind the stop bar. A 6 ft. x 6 ft. [1.8 m x 1.8 m] advance detector is located at a distance back from the stop bar determined by Figure 8-02.8. This range of distance from the stop line within which drivers are often indecisive is known as the dilemma zone. To provide dilemma zone protection on high speed approaches, the detector should be placed at least five seconds travel time from the stop line.

8-02.11 (4) MICROLOOP DETECTORS. Microloop detectors are used at locations where it is undesirable to saw loops in the pavement, such as bridge decks. Typically, 5 probes are used for stop bar detection. Back detectors use 2 probes and speed detectors use 2 sets of 2 probes. Where the end of a bridge divides the detection area, a combination of microloop detectors and an induction loop detector can be used. Typically 2 or 3 probes and a short quadrapole detector are used for this configuration. Figure 8-02.16 shows typical configurations. Microloops have a narrow range of detection, so standard practice is to stagger them 2 ft. [0.6 m] from the centerline of the lane. When possible, probes should not be installed over traffic on overpass bridges.

Microloops require special lead-in cables that are continuous from the probes to the controller and are provided with the probes. The quantity of lead-in cable is itemized separately on the D-37 sheet. The total quantity is included in the pay item for loop detector lead-in cable.

Special detection equipment is required for these probes in the controller cabinet. This equipment is available in 2-channel rack mounted units. The 2-channel cards are installed in the same card rack as the induction loop detectors. The probes must have separate card positions since probes and induction loops cannot be combined on the same detector card.

8-02.11 (5) PUSH BUTTON DETECTORS. This is an insulated momentary push button switch mounted in a housing. It is used for pedestrian actuation.

Push button detectors are mounted on traffic signal posts at locations convenient for pedestrian actuation. Where pedestrian signal indications are installed at traffic-actuated intersections, push button actuation is provided at each end of the controlled crosswalk, and the pedestrian crossing and clearance intervals are timed and controlled by a phase of the controller. Signs R10-3B-9, Crosswalk (pedestrian symbol), and R10-3C-9, Crosswalk (walk verbiage) are installed on the signal post above the push button indicating the function of the push button. See Subsection 8-02.9(5) for specifying signal signs.

8-02.12 PULL BOXES. Concrete and preformed pull boxes are shown on Standard Plan 902.20 and are defined in the standard specifications. The type of pull box to be used is specified on the plans and on the D-37 sheet.

It is desirable to locate a pull box out of the traveled way of vehicles. When a pull box is located in the traveled way, auxiliary lanes or shoulders, a concrete pull box is specified. When a pull box is located outside the shoulder, behind curb or guardrail, or in non-mountable islands, a preformed pull box is specified. In impervious soil, a pull box with a concrete bottom (Type II drain) is used with a 2 in. [50 mm] pipe drain to an adjacent ditch, slope, or drain structure. Both concrete and preformed pull boxes can be installed with Type II drains. Three types of Type II drains can be used depending on the adjacent drainage features. Type A is used where there are no adjacent drainage features. Type B is used where the pull box is adjacent to a ditch or slope. Type C is used where the pull box is adjacent to a storm sewer. Regardless of the type of soil, if the intersection is adjacent to any ditch, slope, or drainage structure, at least one pull box in the conduit system should have a Type II drain into the adjacent drainage feature.

The elevation of the controller must be higher than the elevation of any pull box in the conduit run. Pull boxes,

controllers, and other signal appurtenances are not installed in drainage ditches.

The number of pull boxes should be kept to a minimum. Pull boxes are placed at each end of a conduit line under pavement, except where the conduit run terminates in a service pole. A pull box is required adjacent to detectors to permit a splice between the detector leads and the detector lead-in cable from the controller. A pull box is provided near each post base. A pull box is located at the controller and all wiring, except power supply cables, is routed through this pull box. Pull boxes are to be located a minimum of 2 ft. [0.6 m] from the outside edge of the appurtenance they serve to provide a minimum amount of working area and clearance for conduit elbows and bends. Pull boxes for detectors and signal posts are combined in some instances by skewing the conduit to detectors located in or under the pavement from the pull box provided adjacent to the signal post. This is not permitted where the distance involved exceeds 50 to 60 ft. [15 to 18 m]. When two or more intersections are to be interconnected, the pull boxes along the interconnect conduit are placed no more than 200 ft. [60 m] apart.

Pull boxes are sized according to the following criteria. Pull box dimensions are shown in the standard plans.

The smallest preformed pull box is a Class 1 pull box. These boxes are used at locations with twenty-two (22) or fewer entering conductors. These boxes would typically be used for detector lead-ins and terminal boxes for mast arms at the end of a run. Where required, a standard concrete pull box is used.

When there are more than twenty-two (22) but less than sixty-nine (69) entering conductors a Class 2 preformed pull box is used. This box is probably the most frequently used preformed pull box. Where required, a standard concrete pull box is used.

When there are sixty-nine (69) or more entering conductors a Class 3 preformed pull box is used. Where required, a double concrete pull box is used.

When fiber optic cable for signal interconnect is to be installed as part of a project, the Class 5 preformed pull box is used.

8-02.13 CONDUIT SYSTEM. Electrical connections between traffic signals, detectors, the controller, and power supply in each traffic signal installation or system are made by means of conductor cable carried in closed conduit systems. Conductor cable is exposed only on span wire assemblies. A conduit system provides ease of installation, maintenance, and protection from accidental cutting of the conductor cables. Pull boxes are provided to reduce the number of conduit runs and to facilitate cable pulling and splicing detector leads.

8-02.13 (1) CONDUIT SIZE. Standard conduit size, except those between a loop detector and the first adjacent pull box to the loop detector, is 4 in. [100 mm]. Except for unusual cases, it is preferable to limit the maximum conduit size to 4 in. [100 mm]. When more area is required than is available in this size conduit, parallel lines of conduit providing the required area are used. "Pushed" conduits are 4 in. [100 mm] or larger. A 4 ft. x 8 ft. [1.2 m x 2.4 m] area is required for pushing conduit.

Conduit, used solely for loop detectors, can be 1 in. [25 mm]. A conduit run is required for each loop detector. Conduit used solely for interconnect cable, can be 2 in. [50 mm].

Conduit "in median" is placed on the existing surface prior to the backfilling of the median or island in which it is located. If conduit is being installed in an existing median, use conduit in trench or pushed conduit as required.

8-02.13 (2) CONDUIT LOCATIONS. Pavement crossings are kept to a minimum. Where alternate conduit locations can achieve the same results, a rough cost comparison is made to determine the most economical plan.

A separate conduit containing the power supply cables is provided from the power supply assembly to the controller. It may run directly from the service pole to the controller without entering a pull box unless the distance from the power supply to the controller is greater than 200 ft. [60 m]. Pull boxes are provided so that conduit runs are no more than 200 ft. [60 m] long. Two 4 in. [100 mm] conduits are provided from the first pull box to the controller.

Conduit slopes are determined in the field by the Engineer.

8-02.14 CONTROL AND POWER CABLE.

8-02.14 (1) CONTROL CABLE. All cable runs are continuous between the signal appurtenances and the controller, except for the cables to loop detectors where splices are required with the detector leads. This reduces maintenance and improves servicing by eliminating most splicing. The provision of separate conductors to each signal head allows the use of one wire size by reducing the voltage drop to a minimum. Number 12 AWG [4 mm^2] conductors are used to impart the proper strength to the multi-conductor cables for pulling through conduit.

The number of conductors required for traffic signal equipment is as follows:

- Vehicle signal - 7
- Pedestrian signal - 5
- Push button detector - 2
- Loop detector lead-in cable - 2 - #14 AWG [2.5 mm^2]
- Loop detector in-duct - 1 - #14 AWG [2.5 mm^2]
- Remote On-Off switch - 3
- Pre-timed Interconnection - 7
- Actuated Interconnection - 12
- Closed loop system interconnection - 3 pair conductor #16 AWG [12.5 mm^2]
- Luminaires on signal posts - 2

The number of various cable combinations is kept to a minimum, preferably no more than four types for each contract, and preferably cables with two, five and seven conductors. These combinations have had the most frequent use and are more likely to be available to contractors. The maximum length of cable in the fewest possible sizes generally will result in lower unit bid prices as the cable is furnished in reels of minimum length.

Available multi-conductor cable combinations and their cross-sectional areas are given in Table 8-02.5 in Figure 8-02.14.

8-02.14 (2) POWER CABLE. Single conductor cable is used for power cable. Three insulated power cables are required for each traffic signal installation to supply 120 volt, 60 Hz, single-phase alternating current to the controller cabinet. Minimum conductor size for power cable is #8 AWG [10 mm^2]. Larger sizes may be required where power requirements are high or where power must be carried over a distance where voltage drop is a consideration. See Subsection 8-02.16 for sizing power supply cables.

The maximum allowable voltage drop from the power source to the controller is five percent in order to ensure a high efficiency of operation and long life of the electrical components of the controller.

The voltage drop in any electrical circuit is directly dependent upon current and wire resistance. According to Ohm's Law the voltage drop in a line is equal to the current in amperes multiplied by the resistance of the line in ohms:

$E = I \times R$
E = Voltage
I = Current (in amperes)
R = Resistance (in ohms)

The areas of wires in circular mils [mm^2] and the resistance in ohms per 1000 ft. [1000 m] to be used in calculations are shown in Figure 8-02.13.

The voltage drop caused by loads should not exceed five percent of the applied voltage at the cabinet. A low voltage drop causes equipment and lamps to operate more efficiently and last longer.

8-02.14 (3) EXAMPLE TO DETERMINE VOLTAGE DROP.

Given:
300 ft. [90 m] from power source to controller cabinet
#4 AWG [25 mm^2] Power Supply Cable

1 Controller Unit W/Acc.	4.0 amps (from Subsection 8-02.15)
10 Signal Lamps	13.0 amps
4-150 watt HPS Luminaires	5.2 amps
Cabinet Fan, Outlet & Lamp	2.0 amps
Total	24.2 amps
Factor of Safety	1.3
Maximum	31.5 amps

Voltage Drop = I (amps) x R (resistance)
$V_{ENGLISH}$ = 31.5 amps x 2 x 300 ft x 0.31 ohms/1000 ft = 5.9 volts
V_{METRIC} = 31.5 amps x 2 x 90 m x 0.88 ohms/1000 m = 5.0 volts

8-02.14 (4) GROUND WIRE. A #6 AWG [16 mm^2] solid or stranded neutral wire, in conduit, is used to connect overhead mounted signal heads on bridge structures to the controller ground. A controller mounted on a structure is grounded by means of a #1 AWG [50 mm^2], solid or stranded neutral wire in conduit connected to a ground rod in the first pull box located off the structure, providing the grounding distance does not exceed 200 ft. [60 m]. Over this distance, a larger size wire is used as determined by calculation. Number 6 AWG [16 mm^2], solid or stranded neutral wire is used to electrically bond all steel conduits in pull boxes to the power company ground. A #6 AWG [16 mm^2] solid or stranded neutral wire is provided in all PVC conduits to provide a ground circuit from each post to the ground buss in the controller cabinet. Plan quantities are not computed for ground wire, but conduit should be sized accordingly (see Table 8-02.5 in Figure 8-02.14).

8-02.15 CIRCUIT BREAKER TRIP RATING.

8-02.15 (1) AT CONTROLLER. Separate the total amperage load into:

- Controller Breaker - Controller with accessories, and signal lamps.
- Lighting Breaker - Luminaires.
- Auxiliary Breaker - Cabinet fan, lamp and outlet. (15 amps)

Amperage requirements for signal equipment are shown in Table 8-02.3 in Figure 8-02.13. To determine the maximum number of lamps illuminated during any one interval of the time cycle, total the number of lamps for each signal head as follows:

- Three-Section Head - 1 Lamp
- Four-Section Head - 2 Lamps
- Five-Section Head - 2 Lamps

Multiply each amperage load by 1.3 to determine breaker rating. Controller and auxiliary circuit breakers are required. When luminaires are specified on signal posts, a separate lighting control cabinet is provided on the outside of the controller cabinet containing a circuit breaker, photocell and other equipment as required. Electrical power to the luminaires is controlled through the photocell switch.

The breaker rating for the controller, auxiliary and lighting breakers are to be shown on the D-37C sheet. The auxiliary breaker is specified as 15 amps. See Table 8-02.4 in Figure 8-02.13 for sizing controller and lighting breakers.

8-02.15 **(2) AT POWER SUPPLY.** Circuit breakers at the power supply are to protect the power supply cables. Trip ratings of the circuit breakers are determined by the area of the power cables as determined in Subsection 8-02.16. Main Breaker trip ratings are shown in Table 8-02.2 in Figure 8-02.13.

The circuit breaker frame size should be 50 amps for breaker ratings up to 50 amps and 100 amps for breaker ratings above 50 amps.

8-02.16 CABLE SIZE FROM POWER SUPPLY TO CONTROLLER. Power to the controller is supplied through three single-conductor cables. The maximum factored amperage for the installation is determined by totaling required amperage for the controller(s), accessories, signal lamps, luminaires, and cabinet fan, lamp and outlet and multiplying the total by 1.3. Use Table 8-02.3 in Figure 8-02.13 to determine power requirements. The size of each of the cables is to meet or exceed the computed area as determined by the following formula:

ENGLISH

$$\text{Area (circular mils)} = \frac{L \times I \times 2K}{V}$$

$$= \frac{L \times I \times 24.6}{6}$$

Where

K = 1.2 ohm - circular mils per foot @ 60 C
L = Length from controller to service pole plus (ft) additions
I = Maximum load in amps
V = 6 volts(5%) which is the maximum voltage drop

METRIC

$$\text{Area (mm}^2\text{)} = \frac{L \times I \times K}{V}$$

$$= \frac{L \times I \times K}{6}$$

Where

K = 0.04125 (Metric Conversion Factor)
L = Length from controller to service pole plus (m) additions
I = Maximum load in amps
V = 6 volts(5%) which is the maximum voltage drop

After the required area is computed, use Table 8-02.2 in Figure 8-02.13 to determine the size wire to be used. If the maximum factored amperage exceeds the maximum load for that wire size as shown in Table 8-02.2, use the wire size required to carry the load.

8-02.17 PREPARATION OF PLANS. Design is accomplished in a logical sequence as shown in Figure 8-02.1 and outlined below.

- Obtain traffic counts from Office of Transportation Management Systems.
- Analyze signal warrants and submit to General Headquarters Design for approval.
- Determine if the intersection is in an interconnect system, existing or future.
- Determine the number of signal phases required to accommodate various traffic movements.
- Determine the method of control; pre-timed or traffic actuated.
- Determine the method of interconnect; time-based coordination, hardwire or closed loop.
- Determine the phasing sequence required to accommodate the various traffic movements. (This may be accomplished in step 4).
- Determine the signal indications, location and type mounting of each signal face.

- Determine the type and location of detectors.
- Determine the location of power supply assembly and signal controller.
- Determine the type and location of pull boxes and conduit runs.
- Determine the number and sizes of conductor cables required.
- Determine the breaker ratings for the power supply assembly and controller.

8-02.17 (1) PRELIMINARY LAYOUT. The first step in beginning the design is preparation of a preliminary layout. This layout is drawn on a reproducible material using a scale of 1" = 20' [ratio of 1:200]. Some intersections may require more than one sheet to include the entire intersection area and design features of approaches that influence the traffic signal design. In this case, additional sheets with match lines are used. If drainage or pavement detail design plans are prepared using a scale of 1" = 20' [ratio of 1:200], reproductions of these plans may be used for design of the traffic signal installation with considerable savings in work and time, provided the reproduction is made at an early design stage before details that are not pertinent to the traffic signal installation have been added to the plans.

Signal faces, posts, detectors, and pull boxes are numbered to provide a means of tabulating quantities. A suggested method of numbering is to number the posts and pull boxes first. Signal faces and detectors are numbered to reflect the associated signal phase number (see Subsection 8-02.6.) Signal heads located in front of left turn auxiliary lanes are numbered to reflect a separate left turn phase even if the left turn phase is not being used. Pedestrian heads are numbered to reflect the phase they are associated with.

The following applicable features are shown on the preliminary layout:

- Pavement outlines, existing and proposed, with lane widths and curb types noted
- Sidewalks, crosswalks, stop lines, lane lines
- Islands, noting type (i.e. raised with 6 in. [150 mm] curb, mountable, flush, etc.)
- Approach grades for all approaches
- Vehicle speeds for all approaches
- Parking conditions
- Bus stops
- Entrances, utilities, drainage structures
- Location of nearby railroad or fire station
- Distance to nearest traffic signals for all approaches
- Land use, such as parking lots, service stations, etc.
- Sight-distance restrictions, including adjacent buildings
- Proposed traffic phasing and type of controller (may be shown on a D-38 sheet)
- Arrows showing pavement lane use
- Location of signal posts, controller, power supply, signal faces and their indications
- Type, size and locations of detectors
- Pull box locations and conduit runs
- Traffic volumes for construction and design years with peak hour
- Title block stating location
- Sign location and type
- Turning radii dimensions
- Existing signals
- Interconnection to other signals
- Right of way limits and type
- North arrow
- All streets identified
- Number signal faces, posts, detectors, and pull boxes.

Preliminary signal layout is furnished to district Traffic for review and recommendations. Representatives of General Headquarters Design are available to furnish advice during design and plan preparation. The preliminary signal layout is approved in the district and one (1) copy of the approved layout will be furnished to

General Headquarters Design.

8-02.17 (2) FINAL PLANS. See Chapter IV for information on preparing final plans. In addition to what is shown on the preliminary plans, the following items should be included:

- D-37A
- D-37B
- D-37C
- D-37D
- Phasing sheet (D-38 series)
- Cut-off field if OL heads are used

8-02.17 (3) STANDARD DRAWINGS AND SPECIFICATIONS. These give details of traffic signal installation practices and equipment, and are designed to provide the best possible installation and procure the best equipment available to ensure long life and high efficiency of operation and maintenance. Modifications or deviations from these standard practices should be detailed on the tracings and/or by job special provisions after obtaining approval from General Headquarters Design.

8-02.17 (4) MODIFYING EXISTING TRAFFIC SIGNAL INSTALLATIONS. The preliminary layout for traffic signal installations that are modifications of existing installations show both the existing and proposed installation. The final plans show existing appurtenances that are to remain in place, be abandoned or removed. Existing features are shown as dashed lines and new features as solid lines. Temporary signals should be investigated and considered when existing signals are to be modified. Existing conduit should not be re-used during signal modifications. New conduit should be designed and installed to accommodate the signal upgrades.

8-02.17 (5) TEMPORARY TRAFFIC SIGNAL INSTALLATIONS. If a street is to be widened or an intersection is to be reconstructed in the predictable future, the temporary traffic signal installation is designed to conform to the final layout, as nearly as is practical, and if future interconnection can be predicted, the temporary traffic signal controller is equipped for this eventuality.

8-02.17 (5) (a) WOOD POLE SPAN WIRE SIGNALS. Temporary signals are normally designed as wood pole span wire signals as shown in the standard plans. Signal phasing, head locations and head configurations are the same as permanent signal installations. Temporary signals may be pretimed or traffic actuated. Silhouette discernment (signal pole) basic lighting as described in Section 8-01 is normally provided unless other temporary or permanent lighting provides adequate lighting for the intersection.

The power supply may be installed on one of the wood span wire poles if it is close to the right of way line or utility company facility. If not, a separate power supply should be installed at the right of way line or utility company facility. If possible, the power supply should be installed to be compatible with future construction.

If the signal controller can be located to be compatible with future construction, then it may be installed on a concrete base at the permanent location.

8-02.17 (5) (b) STEEL SPAN WIRE POSTS. In some cases, steel span wire posts as shown in the standard plans may be used for temporary signals. Where limited right of way or other features exclude the use of guy cables, and poor soil conditions exist or cables must be mounted high on the post, steel posts can be considered. The high cable mounting may be a result of fill slopes or long cable spans. Steel posts are only used where needed due to increased cost. Steel posts and wood poles may be used together in the same signal installation. Steel span wire posts are not used in permanent signal installations.

8-02.17 (6) TEMPORARY SIGNALS DURING UPGRADES. Wherever practical, existing signals should not be taken out of service during signal modifications. Wood pole cable spans may be used as needed to facilitate the modifications. A scaled layout of the temporary signals is included in the plans showing all items, including cables. These installations are paid for as temporary traffic signals, per lump sum.

8-02.17 (7) FUTURE TRAFFIC SIGNAL INSTALLATIONS. At intersections designed for roadway construction and the ten-year projected traffic volumes show a need for traffic signals, provisions for the future signal installation are made. This is done by designing the final installation in a rough form and then providing conduit of the proper calculated size under paved surfaces to be installed with the pavement construction. Pull boxes and post bases are not included in the original construction, unless conditions require their inclusion to avoid undue reconstruction when the final installation is made. An example of original construction for future installation, other than conduit, would be a pull box located within a concrete island or median.

8-02.17 (8) QUANTITIES. When the plans are completed, the quantities of materials required are tabulated on the D-37 sheets. The use of identification symbols on the D-37 sheets eliminates unnecessary repetition as to location of each appurtenance in the tabulation of conduit and cable quantities. Both conduit and cable quantities are carefully calculated, as plan quantities are the basis of payment. It is not necessary to show signal quantities on the "2-B" sheets of roadway plans.

8-02.17 (8) (a) CONDUIT. These quantities are calculated or scaled from the plans to the nearest linear foot [0.5 m]. Measurement is made from center to center of all pull boxes, post bases, and controllers. The center to center distance is modified to allow for the proper amount of conduit required for construction.

- A quantity of 2 ft. [0.5 m] added to the center to center distance provides the length necessary to turn the conduit up to ground level for a Type B or Type C base.
- A quantity of 4 ft. [1.0 m] added to the center to center distance provides the length necessary to turn the conduit up to ground level and to the top of a Type A base or ground mounted controller cabinet base.
- If the conduit runs between two pull boxes, 1 ft. [0.5 m] is subtracted from the center to center distance at each end, totaling 2 ft. [1.0 m].

8-02.17 (8) (b) CABLE. These quantities are calculated or scaled from the plans to the nearest linear foot [0.5 m]. Measurement is made from center of pull box to center of pull box or center of signal post, controller, or service pole. Cable from the controller to the loop detectors is measured to the first pull box adjacent to the detector where the splice to the detector leads is made. Pole and bracket cable must be used from the signal post base to the luminaire. At the signal post base, the pole and bracket cables are spliced to the 2c - #12 AWG [2c - 4 mm^2] using a fused slip connector assembly as shown in Standard Plan 901.02. Signal heads mounted on the side of mast arm signal posts are provided with conductor cable connection to the controller separate from that provided for the overhead mounted signal head if the side mounted signal does not operate identically with the signal on the mast arm. When the signals operate identically during all signal phases, a 7-conductor cable is provided to the signal head on the mast arm from the controller and a 7-conductor jumper cable is provided from the signal head on the mast arm to the side mounted signal. This is done to ensure the mast arm signal will continue to operate in the event of an accident that disables the side mounted signal. If two signal heads mounted on the same mast arm operate identically during all phases, a 7-conductor jumper cable can be provided between terminal compartments and only one 7-conductor cable is required to the controller. A maximum of two signal heads are allowed per 7-conductor jumper. The cable length for the jumper is included in the cable quantities for that cable run. A signal head located in front of a left turn auxiliary lane has a separate 7-conductor cable to the controller even if a left turn phase is not being used.

Additional cable quantities are added to the center-to-center measurement to provide slack and to provide for the cable to be turned up and connected to terminal strips in the controller, signal head terminal compartments, signal head disconnect hangers, and detectors, or to the service head of the power supply assembly as follows:

- 6 ft. [1.8 m] of each cable passing through each pull box. 3 ft. [0.9 m] if the cable terminates in the pull box, as in Lead-In or In-Duct loop detector cable.
- 8 ft. [2.4 m] of each cable at the controller.
- 13 ft. [4.0 m] of each cable at side mounted and post top mounted vehicular signal heads.
- 10 ft. [3.0 m] of each cable at side mounted and post top mounted pedestrian signal heads.

- 9 ft. [2.7 m] of each cable to pedestrian pushbutton detectors located on posts.
- 21 ft. [6.3 m] of each cable at each signal post with mast arm plus the length of the mast arm or distance to the first signal terminal compartment.
- 35 ft. [10.7 m] of each cable at the service pole supporting the power supply assembly.
- 8 ft. [2.4 m] of each cable when connecting to a pedestal mounted power supply.
- The length required to turn up the post and connect to span wire mounted detectors or signal heads.
- 30 ft. [9.0 m] plus the bracket arm length for cables to luminaires on signal posts.
- 60 ft. [18.0 m] of fiber cable at pull boxes adjacent to signal or splice cabinets.
- 10 ft. [3 m] of fiber cable passing through each pull box.

The cable quantities on each D-37 sheet are totaled to the nearest linear foot [0.5 m]. The total of all D-37 sheets is rounded to the nearest 10 linear feet [5.0 m] on the estimate.

8-02.17 (9) COLOR SEQUENCE. The color sequence, or interval sequence of signal indications showing all possible variations in indications due to phase skipping or auxiliary equipment, is shown on a D-38 sheet which accompanies the plans. Several standard signal phasing and layout (D-38) sheets are available in the MoDOT Traffic Manual. If used, these sheets should be reviewed and modified as necessary according to conditions.

8-02.17 (10) DESIGN CONFLICTS. Conflicts with other design features for proposed locations of various signal appurtenances are carefully checked during plan preparation. In addition, the design is checked to assure that signal faces are not obstructed by other design features, such as lighting poles, bridge piers, lane control signs, etc. Where overhead signal mountings are used, the design is checked to ensure there is no conflict with existing overhead wiring or obscuring of signals by other signal or sign mast arms.

8-02.17 (11) ESTIMATE. After all quantities are computed, an estimated cost (taking into account local conditions which may influence the contract bid) of the completed installation is submitted electronically to General Headquarters Design.

8-02.17 (12) JOB SPECIAL PROVISIONS. These are prepared as required and submitted with the plans.

8-02.17 (13) TITLE SHEET. If the traffic signal installation is planned as a separate contract from other work, a title sheet is prepared in accordance with requirements given in Chapter IV and submitted with the plans.

8-02.17 (14) LETTER OF TRANSMITTAL. The letter of transmittal lists and explains any deviations from standard practice as well as any items requiring special consideration. A letter from the utility company supplying electrical power is submitted with the letter of transmittal. Cost of electrical hook-up should be noted in the letter of transmittal.

8-02.17 (15) SEQUENCE OF SIGNAL PLAN SHEETS. Signal plans should be assembled in the following sequence:

- Plan Sheet
- Quantity Sheet D-37A
- Quantity Sheet D-37B
- Quantity Sheet D-37C
- Quantity Sheet D-37D
- Control Operation D-38 Sheet
- Special Traffic Signal Sheets (if any).